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The vegetation of a relict salt marsh area in the Pisan coast in the context of brackish wetlands of Tuscany

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Abstract

The paper presents the results of phytosociological surveys carried out in Galanchio-Cornacchiaia, a salt marsh area on the Pisan coast (northern Tuscany), which survived the agricultural reclamation. The vegetation surveys confirm the brackish features of the site, while highlighting three substantially different subareas in terms of prevailing vegetation. The phytosociological study allowed the identification of 11 marsh phytocoenoses attributable to 12 associations (*Crypsidetum aculeatae*; *Parapholidetum filiformis*; *Suaedo maritimae-Salicornietum patulae*; *Suaedetum maritimae*; *Puccinellio festuciformis-Halimionetum portulacoidis*; *Puccinellio festuciformis-Sarcocornietum perennis*; *Elytrigio elongatae-Inuletum crithmoidis*; *Limonio narbonensis-Juncetum gerardi*; *Puccinellio festuciformis-Aeluropetum litoralis*, *Junco maritimi-Spartinetum junceae*; *Juncetum maritimi-acuti*; *Phragmitetum australis*). These plant communities are referable to 3 brackish habitats and related subtypes, reported in 92/43 ECC Directive habitats. This biotope, although part of the neighboring area of the Regional Park of Migliarino San Rossore Massaciuccoli, is currently in an extremely precarious balance and threatened by the surrounding agricultural activities. The knowledge of its naturalistic peculiarities and remarkable biodiversity, can contribute to its increased protection and conservation. This study add new data to the knowledge of the brackish vegetation of Tuscany.

Keywords

Coastal habitat, *Juncetea maritimi*, *Phragmito-Magnocaricetea*, phytosociology, *Saginetea maritimae*, *Salicornietea fruticosae*, salt marshes vegetation, *Thero-Salicornietea*

Introduction

The Coastal salt marshes are natural environments of great interest. Usually, they are formed by depressions with saline soil, close to the coastline, flooded in the winter but often dry in the summer (Scott et al. 2014). These environments are characterized by the presence of highly specialized plant communities and often, of rare or endangered plant species (Biondi 1999, Lefeuvre et al. 2003). These habitats are currently under increasing human pressure by urban, industrial and agricultural development (Garbutt et al. 2017). In Tuscany, this has led to a progressive but strong reduction in number and surface of the coastal salt marshes from the beginning of the twentieth century (Progetto Castore, http://www502.regione.toscana.it/castoreapp/).

The "Lame" of the San Rossore Estate represent the largest brackish complex in the Pisan coastal area (Tomei et al. 2004; Bertacchi et al. 2007). Smaller areas are to be added to this macro area, legacy of larger swamps now reclaimed, whose high naturalistic value is increasingly threatened by anthropic activities (Coaro 1987). Among these, the area of Galanchio-Cornacchiaia, located on the southern edge of the Regional Park of Migliarino San Rossore Massaciuccoli, arouses particular interest. Both as it has never been investigated from a vegetational point

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of view, and because it is subject to a progressive order of transformation threats. The aim of this study is to investigate the area from the phytosociological point of view in order to implement the knowledge on brackish wetlands of Tuscany.

Methods

Study area

The toponym of Galanchio indicates a brackish area that extends for about twenty hectares near the Cornacchiaia Reserve in the Tombolo Estate of the Regional Park of Migliarino, San Rossore, Massacciuccoli (PI), on the right bank of the Navicelli canal (central point: 43° 35. 467' N, 10° 18.984' E). The area is located about 800 meters from the sea line, at an altitude from −0.6 to 1 m asl and is characterized by two semi-permanent ponds: Galanchio W, about 3 hectares, and Galanchio E, about 2 hectares.

Moving away from the sea, proceeding eastwards, there is another semi-permanent brackish pond of about 2 hectares, here called Cornacchiaia (Fig. 1).

The whole area represents the remains of a much larger brackish area of ancient ecclesial properties which consisted of extensive woods and wild marshes. This landscape survived until the early 1900s, when the massive reclamation interventions began to change the physiognomy of the area. The progressive disappearance of the wetlands and the large forest followed, and the land was subsequently used for agricultural purposes (Rupi 1995).

The landscape of the area, from the reclamation onwards, had several changes until the end of the 80s of the last century. In 1954, 26 years after the reclamation, the Galanchio area was completely dry and used for agricultural purposes. Starting from 1978 the first wetland, corresponding to Galanchio E, reappeared within the agricultural matrix. Since 1988 the reappearance of the second area, corresponding to Galanchio W, has been observed. Since then, there have been no significant changes in their extent. Currently, the two brackish ponds of Galanchio are included within agricultural areas and consequently very disturbed at their edges by agricoltural works. The Cornacchiaia pond, located within a sparse wooded matrix, is much less disturbed (Fig. 2).

From a pedological point of view, the whole area falls within an ancient humid retrodunal depression, consisting of mixed sediments. The three ponds are instead attributable to silty sand deposits and the analysis of electrical conductivity on soil samples surrounding the study area, reveals an average salinity of 1800 µS / cm (AA.VV. 2005).

For the climatic characterization the thermo-pluviometric data of the meteorological station of San Piero a Grado (Pisa, Italy) were used. The total average annual rainfall, for the period 1997-2016, exceeds 934.9 mm with a maximum rainfall in the autumn. The average annual temperature is 14.5° C, with a maximum of about 30° C in July and August.

The thermoudogram shows a period of summer drought with water deficit from June to September. Based on the bioclimatic classification of Pesaresi et al. (2017), the study area bioclimate belongs to the Mediterranean

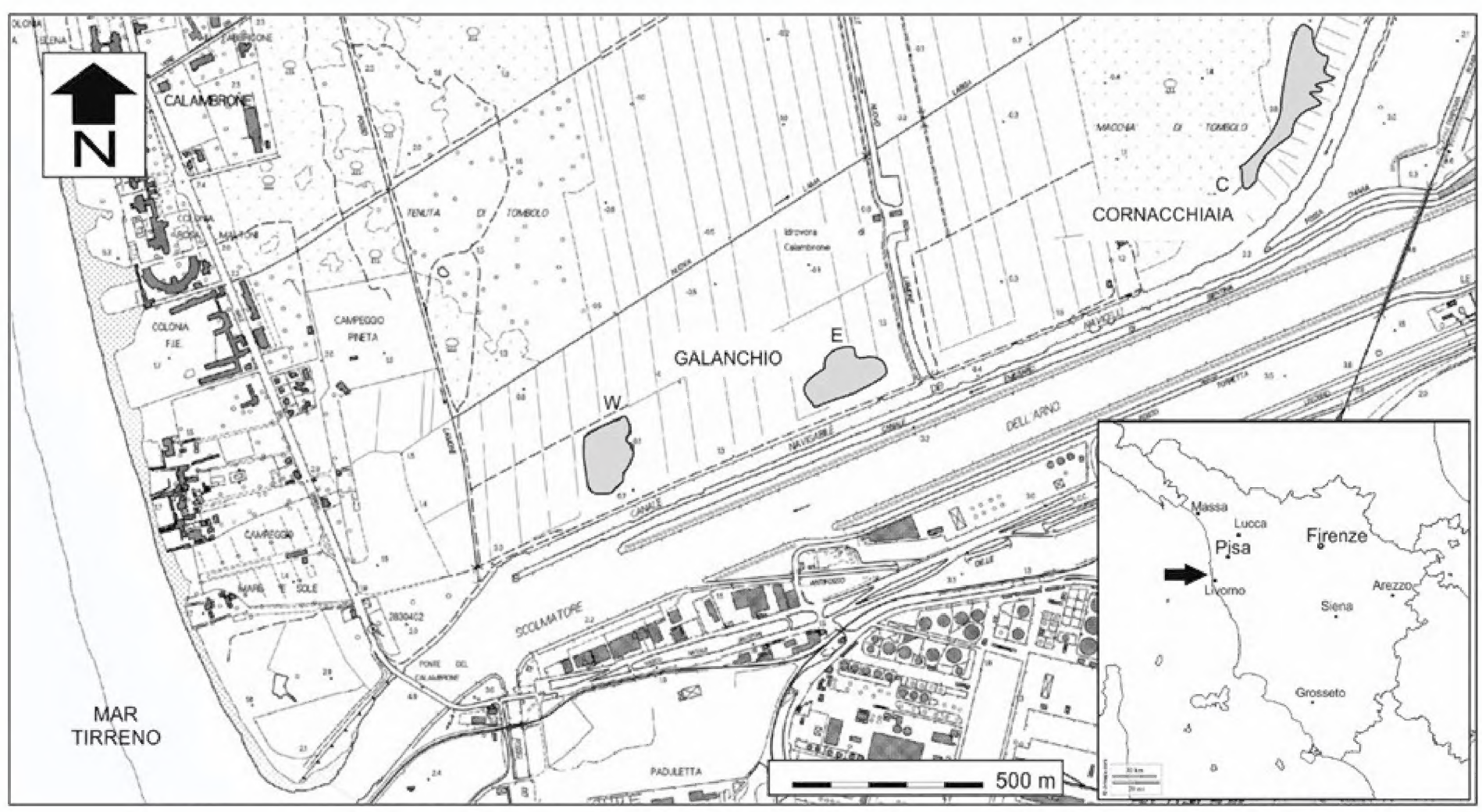

Figure 1. Geographic position of the study area and the three brackish ponds investigated (W, E, C) (Map data Geoscopio Regione Toscana, CTR).

macro-bioclimate, mesomediterranean thermotype, lower subhumid ombrotype.

Data collection and processing

A total of 65 relevés were carried out in homogeneous areas within the brackish portions of the area excluding the transition areas. The method followed the Braun-Blanquet phytosociological approach (Braun-Blanquet 1983; Westhoff and van der Maarel 1978; Biondi 2011). In order to identify the different groupings, data relevés were analyzed with PAST 3.14 software (matrix of 61 species x 65 relevés. Cluster analysis, using UPGMA and Bray-Curtis index were assessed. Subsequently, the Detrended Corrispondence Analysis (DCA) was applied to the matrix data, with the aim of obtaining an evaluation to see what information it may provide additional to that given by the cluster analysis. For multivariate analysis purposes, the cover values were transformed according to the method proposed by van Der Maarel (1979). Plant species nomenclature follows Bartolucci et al. (2018) and the subsequent updates summarized in the Portal to the Flora of Italy (2019).

For the syntaxonomic references at the ranks of alliance, order and class, we referred to Biondi et al. (2014) and Mucina et al. (2016). The names of syntaxa comply with the International Code of Phytosociological Nomenclature (ICPN) (Theurillat et al. 2020). For the correlation between vegetation types and habitat types, we referred to the Italian Interpretation Manual for the Habitats of Directive 92/43/ EEC (Biondi et al. 2009; Biondi et al. 2012).

Results

The cluster analysis showed, with good significance, eleven different brackish plant communities corresponding to eleven association, belonging to five classes (Fig. 3). Detrended Correspondence Analysis, confirmed the cluster subdivision of the detected vegetation, and separated it quite clearly into three groups. These correspond to three different habitats (sensu Directive 92/43/EEC): Habi-

Figure 2. The agro-forested landscape of the study area (dot line indicates areas with saline soils) (Map data 2019 Google Earth Pro).

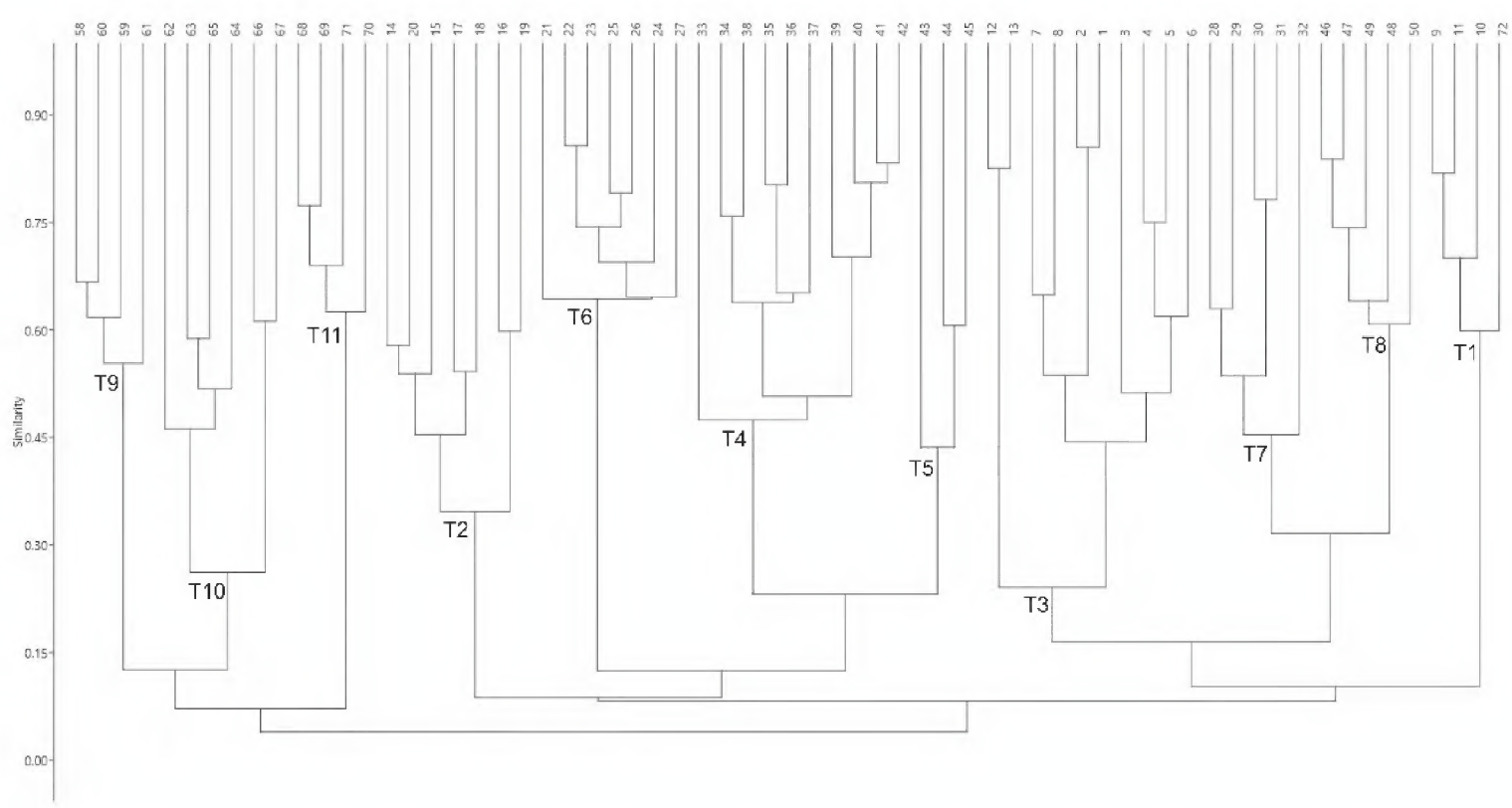

Figure 3. Cluster Analysis graphic applied to the 65 relevés of the study area (the abbreviations in the branches correspond to the numbers of the tables).

tat 1310 – *Salicornia* and other annuals colonizing mud and sand; Habitat 1410 – Mediterranean salt meadows (Juncetalia maritimi) and Habitat 1420 – Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosae*) (Fig. 4).

This set of phytocoenoses falls into the following typologies: ephemeral grasslands with halonitrophilous annuals; pioneer grasslands with annual grassworts; halophilous succulent dwarf shrubs communities; hemicryptophyte salt grasslands; reedbeds dominate by *Phragmites australis*.

Ephemeral grasslands with halonitrophilous annuals (*Saginetea maritimae*)

CRYPSIDETUM ACULEATAE (Bojko 1932 n.n.) Wenzel 1934 (Tab. 1, Annex I Habitat: 1310).

These almost monospecific phytocoenoses are found only in the Cornacchiaia area, in three little ponds that dry up completely in the summer. On their surface some therophytic coenoses dominated by *Sporobolus aculeatus* (L.) P. M. Peterson (= *Crypsis aculeata* (L.) Aiton.) are identifiable. This species is a rather rare annual prostrate grass, also reported for the neighboring Tenuta of San Rossore although only as a sporadic presence in drainage discharges (Tomei et al. 2004), abundant and widespread species of the annual glasswort *Thero-Salicornietea*, such as *Salicornia perennans* or *Suaeda maritima*, and species of the *Juncetea maritimi* are also found. From a syntaxonomic point of view, these populations can be referred to the *Crypsidetum aculeatae* association, a coenosis found only for the Adriatic, Ionian, Sardinia and high Lazio coasts (Biondi et al. 1992; Corbetta et al. 1992; Frondoni and Iberite 2002; Tomaselli et al. 2010). In Tuscany this association is reported only for the Padule Orti-Bottagone (LI) (Viciani and Lombardi 2001).

Table 1. *Crypsidetum aculeatae* (Bojko 1932 n. n.) Wenzl 1934.

Relevé number	72	9	10	11	Presence
Site	C	C	C	C	
Area (m²)	4	4	4	4	
Cover (%)	100	100	100	100	
Diagnostic of association					
Sporobolus aculeatus (L.) P.M.Peterson	5	4	3	4	4
Other species					
Salicornia perennans Willd. subsp. *perennans*	.	.	1	+	2
Suaeda maritima (L.) Dumort.	.	+	.	r	2
Thinopyrum acutum (DC.) Banfi	.	+	r	.	2
Polypogon monspeliensis (L.) Desf.	.	1	.	+	2
Bolboschoenus maritimus (L.) Palla	.	r	.	r	2
Spergularia marina (L.) Griseb	.	.	.	+	1
Hordeum marinum Huds.	.	.	.	r	1
Juncus gerardi Loisel. subsp. *gerardi*	r	.	.	.	1

PARAPHOLIDETUM FILIFORMIS Brullo, Scelsi & Siracusa 1994. (Tab. 2, Annex I Habitat: 1310).

This type of vegetation consists of ephemeral grasslands on humid soils with low salinity. In the study area it is relegated to the halomorphic soils of the East pond, which is wet during the winter-spring period but never submerged. Here, the phytocoenosis makes catenal contact with perennials formations of *Salicornietea fruticosae* and with the annual ones of the *Thero-Salicornietea*. This association, reported for other brackish coastal sectors of the peninsula (Lazio, Sicily, Puglia) (Frondoni and Iberite

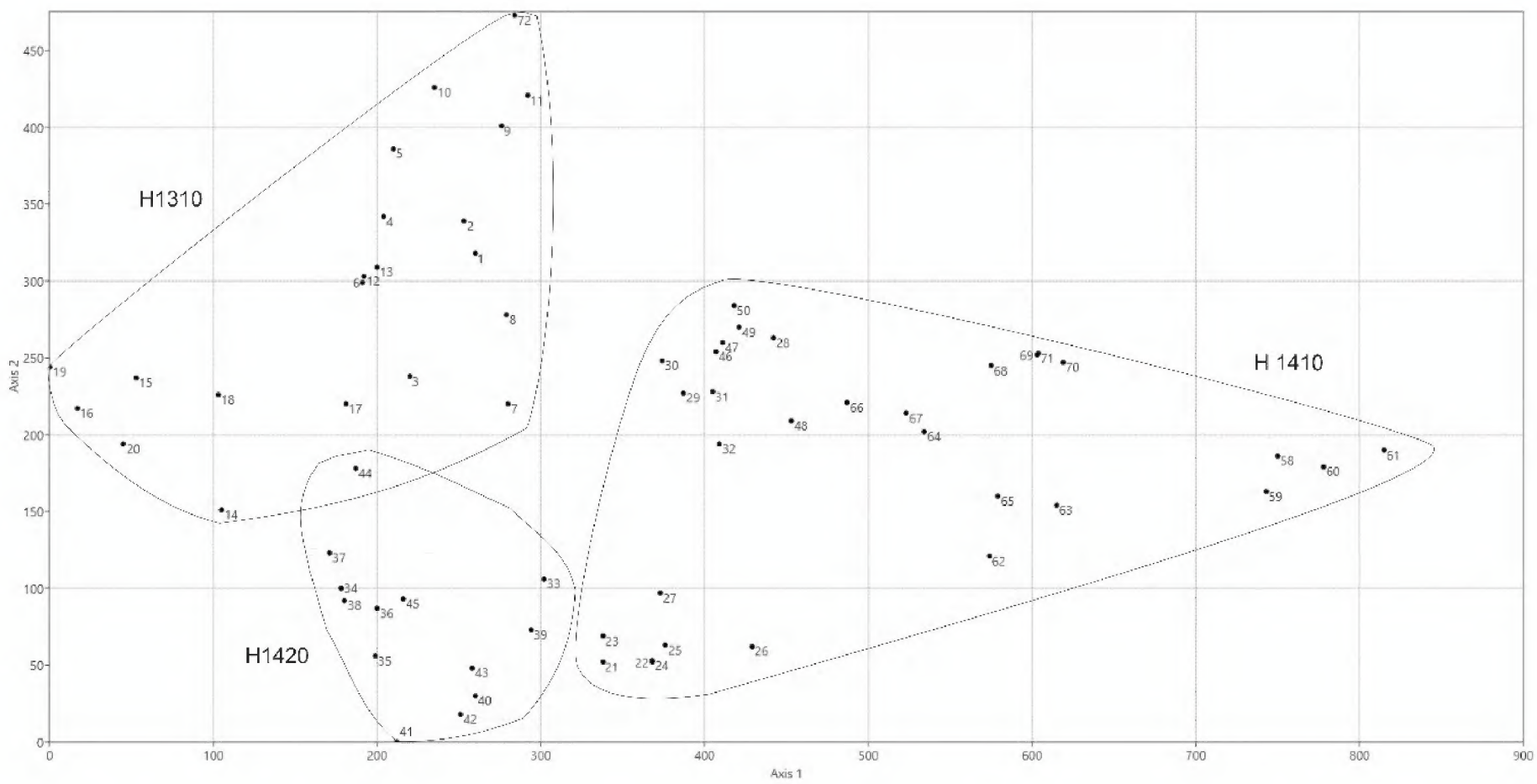

Figure 4. Detrended Correspondence Analysis graphic applied to the 65 relevés of the study area (the three point clouds identified refer to three supposed habitats).

Table 2. *Parapholidetum filiformis* Brullo, Scelsi & Siracusa 1994.

Relevé number	14	15	16	17	18	19	20	Presence
Site	GE	GE	GE	GE	GE	GW	GW	
Area (m²)	4	4	4	4	4	4	4	
Cover (%)	100	70	100	100	80	60	80	
Diagnostic of association								
Parapholis filiformis (Roth) C.E. Hubb.	3	2	+	2	2	+	3	7
Charact. of higher units								
Hordeum marinum Huds.	1	1	2	+	2	2	+	7
Spergularia marina (L.) Griseb	.	1	.	.	.	.	+	2
Other species								
Avena sterilis L. subsp. *sterilis*	r	.	+	r	+	.	+	5
Plantago coronopus L.	.	+	+	.	r	+	2	5
Lolium multiflorum Lam.	+	.	2	1	+	.	.	4
Atriplex prostrata DC.	.	.	.	1	1	.	r	3
Trigonella sicula (Turra) Coulot & Rabaute	.	+	+	.	.	1	.	3
Trifolium squamosum L.	.	.	1	.	+	.	.	2
Salsola inermis L.	.	.	.	.	1	.	r	2
Suaeda maritima (L.) Dumort.	.	+	.	.	.	.	r	2
Bromus squarrosus L. subsp. *squarrosus*	.	.	.	r	.	.	.	1
Thinopyrum acutum (DC.) Banfi	+	.	.	.	.	.	.	1
Elymus repens (L.) Gould subsp. *repens*	.	.	.	.	.	+	.	1
Gaudinia fragilis (L.) P. Beauv.	+	.	.	.	.	.	.	1
Helminthotheca echioides (L.) Holub	.	.	.	.	+	.	.	1
Poa trivialis L.	.	.	.	.	.	r	.	1
Puccinellia festuciformis (Host) Parl.	.	.	.	r	.	.	.	1
Sonchus asper (L.) Hill subsp. Asper	.	+	.	.	.	.	.	1
Aeluropus littoralis (Gouan) Parl. subsp. *littoralis*	.	.	.	2	.	.	.	1
Galatella tripolium (L.) Galasso, Bartolucci & Ardenghi	.	.	.	.	r	.	.	1

2002; Brullo and Giusso del Galdo 2003; Tomaselli et al. 2010) is new for Tuscany.

Pioneer grasslands with annual grassworts (*Thero-Salicornietea*)

SUAEDO MARITIMAE-SALICORNIETUM PATULAE (Brullo & Furnari 1976) Géhu & Géhu-Franck 1984 (Tab. 3, Annex I Habitat: 1310).

The *Suaedo maritimae-Salicornietum patulae* association is common to all three brackish areas, although with different extensions due to a different degree of drought in the summer. Where greater are the surfaces that dry up and where greater is the rise of the salts, as occurs in the eastern Galanchio pond, the association reaches the maximum diffusion and coverage. Among the species present in the phytocenosis, the annual halophilous *Salicornia perennans* subsp. *perennans* and *Suaeda maritima* are dominant, although, not infrequently, an important cover of perennials species such as *Aeluropus littoralis* subsp. *littoralis* and *Puccinellia festuciformis* can be observed.

Suaedo maritimae-Salicornietum patulae is the most widespread association of brackish areas in the Mediterranean area (Gehù 1992) and, consequently, for the Italian coastal areas also (Géhu et al. 1984; Biondi 1999). In Tuscany, the association has been identified both in the neighboring Tenuta di San Rossore (Sani and Tomei 2006) and in other brackish areas of the coastal sector (Arrigoni et al. 1985; Viciani and Lombardi 2001; Andreucci 2004).

SUAEDETUM MARITIMAE (Cornad, 1935) Pignatti 1953 (Tab. 4, Annex I Habitat: 1310).

This community is found on humid and well nitrified soils with abundant organic substance. Here, *Suaeda maritima* forms large spots, accompanied by a few other species of the *Thero-Salicornietea*, such as Soda inermis and Salicornia perennans. In the investigated area it appears not very widespread and, for Tuscany, it has previously been reported only in the Orbetello Lagoon (Gr) (Andreucci, 2004).

Halophilous succulent dwarf shrubs communities (*Salicornietea fruticosae*)

PUCCINELLIO FESTUCIFORMIS-SARCOCORNIETUM PERENNIS (Br.-Bl. 1931) Géhu 1976 (Tab. 5, Annex I Habitat: 1420).

This association is uneven in both Galanchio ponds, with different extensions but always limited to the areas where the soil remains humid also in summer. It is not present in the Cornacchiaia area, where in Summer, the soils dry out completely. This plant community is characterized by *Salicornia perennis* Mill. subsp. *perennis*, a perennial prostrate species, which often forms the characteristic isodiametric "carpets" in a matrix of species

Table 3. *Suaedo maritimae-Salicornietum patulae* (Brullo et Furnari 1976) Géhu et Géhu-Franck 1984.

Relevé number	1	2	3	4	5	6	7	8	Presence
Site	GE	GE	GE	GE	GE	GE	GW	GW	
Area (m²)	4	4	4	4	4	4	4	4	
Cover (%)	70	80	80	100	100	100	100	100	
Diagnostic of association									
Salicornia perennans Willd. subsp. *perennans*	2	2	1	2	1	1	2	3	8
Suaeda maritima (L.) Dumort.	2	2	1	1	1	+	r	+	8
Charact. of higher units									
Limonium narbonense Mill.	.	r	.	.	.	.	1	1	3
Other species									
Aeluropus littoralis (Gouan) Parl. subsp. *littoralis*	.	1	.	1	+	+	1	1	6
Puccinellia festuciformis (Host) Parl.	.	.	+	+	.	+	+	1	5
Spergularia marina (L.) Griseb	.	.	.	2	2	1	.	.	3
Parapholis filiformis (Roth) C.E. Hubb.	+	.	+	.	.	.	+	.	3
Hordeum marinum Huds.	.	.	+	1	.	1	.	.	3
Poa trivialis L.	.	.	.	.	.	+	r	.	2
Juncus gerardi Loisel. subsp. *gerardi*	.	.	.	.	.	.	1	r	2
Thinopyrum acutum (DC.) Banfi	.	.	.	.	.	.	+	.	1
Gaudinia fragilis (L.) P. Beauv.	.	.	.	.	.	.	+	.	1
Lolium multiflorum Lam.	.	.	+	.	.	.	.	.	1
Bolboschoenus maritimus (L.) Palla	.	.	r	.	.	.	.	.	1
Salicornia procumbens Sm. subsp. *procumbens*	.	.	.	.	.	r	.	.	1
Spergularia media (L.) C. Presl	.	.	+	.	.	.	.	.	1
Galatella tripolium (L.) Galasso, Bartolucci & Ardenghi	.	.	.	.	r	.	.	.	1
Soda inermis Fourr.	.	.	+	.	.	.	.	.	1
Halimione portulacoides (L.) Aellen	.	.	.	.	.	.	1	.	1

Table 4. *Suaedetum maritimae* (Cornad, 1935) Pignatti 1953.

Relevé number	12	13	Presence
Site	GE	GE	
Area (m²)	4	4	
Cover (%)	80	80	
Diagnostic of association			
Salicornia perennans Willd. subsp. *perennans*	+	+	2
Suaeda maritima (L.) Dumort.	3	4	2
Other species			
Soda inermis Fourr.	+	1	2
Halimione portulacoides (L.) Aellen	+	+	2
Atriplex prostrata Boucher ex DC	+	+	2
Aeluropus littoralis (Gouan) Parl. subsp. *littoralis*	.	r	1
Puccinellia festuciformis (Host) Parl.	r	.	1
Polypogon monspeliensis (L.) Desf.	+	.	1

such as *Puccinellia festuciformis*, to which are added *Halimione portulacoides*, *Aeluropus littoralis* and *Parapholis filiformis*. In the scientific literature, this association has sometimes been assigned to *Sarcocornietum deflexae* (Géhu and Biondi 1994), assuming that only *Sarcocornia fruticosa* var. *deflexa* was present in the Mediterranean coasts, while *Salicornia perennis* was typical of the Atlantic coasts only. In agreement with other authors (Viciani and Lombardi 2001; Frondoni and Iberite 2002) we prefered to attribute this phytocenosis to *Puccinellio festuciformis-Sarcocornietum perennis*, recognizing in it the presence of *Salicornia perennis* (= *Sarcocornia perennis*). This association is quite widespread along the Italian brackish coastal areas (Gehù et al. 1984) and in Tuscany it is also present in other sectors of the southern coast of the region (Arrigoni et al. 1985; Viciani and Lombardi 2001; Andreucci 2004).

PUCCINELLIO FESTUCIFORMIS-HALIMIONETUM PORTULACOIDIS Géhu et al. 1992 (Tab. 6, Annex I Habitat: 1420).

This association is closely linked to the association described above and its environmental context. Found only in the eastern pond of Galanchio, it is characterized by the dominance of *Halimione portulacoides* over *Salicornia perennis* and is located at the border of brackish areas with agricultural disturbance. This association is not very frequent in Italy (Corbetta and Pirone 1999; Frondoni and Iberite 2002) and in Tuscany it is reported only in Palude di Orti-Bottagone (LI) (Viciani and Lombardi 2001).

Hemicryptophyte salt grasslands (*Juncetea maritimi*)

ELYTRIGIO ELONGATAE-INULETUM CRITHMOIDIS Br.-Bl. (1931) 1952) (Tab. 7, Annex I Habitat: 1410).

Along the drainage ditches surrounding the two Galanchio ponds, and often inside the ditches themselves, phytocoenoses characterized by a high coverage of *Limbarda crithmoides*, associated with *Thinopyrum acutum* (= *Elytrigia atherica* (Link) Kerguélen) and to a lesser extent *Limonium narbonense* can be found. This plant community can be referred to E*lytrigio elongatae-Inuletum crithmoidis*, although *Thinopyrum elongatum* (= *Elytrigia elongata* (Host) Nevski) has never been

Table 5. *Puccinellio festuciformis-Sarcocornietum perennis* (Br.-Bl. 1931) Géhu 1976.

Relevè number	33	34	35	36	37	38	39	40	41	42	Presence
Site	GW	GW	GW	GW	GE	GE	GE	GE	GE	GE	
Area (m²)	4	4	4	4	4	4	4	4	4	4	
Cover (%)	100	70	100	70	100	100	100	100	100	100	
Diagnostic of association											
Salicornia perennis Mill. subsp. *perennis*	3	3	4	4	3	2	4	5	5	5	10
Puccinellia festuciformis (Host) Parl.	2	.	+	+	2	1	+	.	.	.	6
Charact. of higher units											
Aeluropus littoralis (Gouan) Parl. subsp. *littoralis*	.	.	+	r	.	.	1	1	.	.	4
Halimione portulacoides (L.) Aellen	.	1	+	.	.	1	.	.	.	.	3
Galatella tripolium (L.) Galasso, Bartolucci & Ardenghi	+	.	.	.	.	.	.	.	.	.	1
Atriplex prostrata DC.	.	.	.	+	.	.	.	.	.	.	1
Limonium narbonense Mill.	r	.	.	.	.	.	1		.	1	3
Other species											
Parapholis filiformis (Roth) C.E. Hubb.	.	2	2	1	2	2	.	.	+	+	7
Thinopyrum acutum (DC.) Banfi	.	.	.	.	.	.	1	+	.	1	3
Salicornia perennans Willd. subsp. *perennans*	.	r	.	.	.	+	.	.	.	.	2
Spergularia marina (L.) Griseb	.	.	.	+	1	.	.	.	.	.	2
Centaurium tenuiflorum (Hoffmanns. & Link) Fritsch	.	.	.	.	.	.	.	r	.	r	2
Bolboschoenus maritimus (L.) Palla	+	.	.	.	.	.	.	.	.	.	1
Polypogon monspeliensis (L.) Desf.	1	.	.	.	.	.		.	.	.	1
Suaeda maritima (L.) Dumort.	.	1	.	.	.	.	.	.	.	.	1
Hordeum marinum Huds.	.	.	.	.	1	.	.	.	.	.	1
Juncus gerardi Loisel. subsp. *gerardi*	.	.	.	.	.	.	+	.	.	.	1

Table 6. *Puccinellio festuciformis-Halimionetum portulacoidis* Géhu et al. 1992.

Relevé number	43	44	45	Presence
Site	GE	GE	GE	
Area (m²)	4	4	4	
Cover (%)	80	60	80	
Diagnostic of association				
Halimione portulacoides (L.) Aellen	2	3	4	3
Puccinellia festuciformis (Host) Parl.	+	+	.	2
Charact. of higher units				
Salicornia perennis Mill. subsp. *perennis*	+	1	1	3
Aeluropus littoralis (Gouan) Parl. subsp. *littoralis*	.	.	+	1
Other species				
Salicornia perennans Willd. subsp. *perennans*	.	+	.	1
Limonium narbonense Mill.	1	.	.	1
Dittrichia viscosa (L.) Greuter subsp. *viscosa*	1	.	.	1
Suaeda maritima (L.) Dumort.	.	2	.	1
Thinopyrum acutum (DC.) Banfi	1	.	.	1

found. The association is not very widespread along the Italian coasts and, even less so in the Tuscan ones, where it has been reported in a couple of stations (Viciani and Lombardi 2001; Foggi et al. 2006). It should also be emphasized that these populations, developing near or inside the drainage channels, are annually destroyed by agricultural procedures.

LIMONIO NARBONENSIS-JUNCETUM GERARDI Géhu et Biondi 1994 (Tab. 8, Annex I Habitat: 1410).

In the area inside the eastern pond of the Galanchio and to a limited extent in that of the Cornacchiaia, sub-halophilous rushes dominated by *Juncus gerardi* subsp. *gerardi* can be observed. These "islands", characterized by the constant presence of *Limonium narbonense*, are surrounded by populations of *Aeluropus littoralis* subsp. *littoralis*, which, however, penetrates them abundantly. It has been described in Italy for the Adriatic and Tyrrhenian coasts, although in the latter it appears less common (Géhu and Biondi 1996; Frondoni and Iberite 2002).

PUCCINELLIO FESTUCIFORMIS-AELUROPETUM LITORALIS (Corb. 1968) Géhu et Costa 1984 in Géhu et al. 1984 (Tab. 9, Annex I Habitat: 1410).

Around the populations of *Limonio narbonensis-Juncetum gerardi* and in catenal contact with the reed beds of the northern edge of the eastern pond of Galanchio, there are large surfaces with dense covers of *Aeluropus littoralis*. This plant community occupies surfaces that remain humid also during the summer. The high coverage of *Aeluropus littoralis* and the presence of *Puccinellia festuciformis*, although not constant, leads us to attribute this phytocoenosis to the association *Puccinellio festuciformis-Aeluropetum litoralis*. This, despite the frequent presence of *Bolboschoenus maritimus* which would differentiate it from the characterization described by Gehù et al. (1984) and Poldini et al. (1999) and Sciandrello and Tomaselli (2014) for these phytocoenoses on the Adriatic side. In Tuscany this association has never been described.

JUNCO MARITIMI-SPARTINETUM JUNCEAE (O. de Bolòs 1962) Filigheddu, Farris & Biondi 2000 (Tab. 10, Annex I Habitat: 1410).

Only in the westernmost pond, on permanently humid surfaces, dense populations of the neophyte *Sporobolus pumilus* (Roth) P.M.Peterson & Saarela (= *Spartina versicolor* Fabre), almost always associated with *Juncus*

Table 7. *Elytrigio elongatae-Inuletum crithmoidis* Br.-Bl. (1931) 1952.

Relevé number	21	22	23	24	25	26	27	Presence
Site	GW	GW	GW	GW	GE	GE	GE	
Area (m²)	4	4	4	4	4	4	4	
Cover	100	100	100	100	100	100	100	
Diagnostic of association								
Limbarda crithmoides (L.) Dumort. subsp. *longifolia* (Arcang.) Greuter	3	4	4	5	4	4	3	7
Charact. of higher units								
Thinopyrum acutum (DC.) Banfi	1	+	+	+	1	1	+	7
Limonium narbonense Mill.	1	+	+	.	1	+	+	6
Galatella tripolium (L.) Galasso, Bartolucci & Ardenghi	+	.	.	.	.	.	+	2
Juncus maritimus Lam.	.	+	.	.	.	r	.	2
Other species								
Salicornia perennis Mill subsp. *perennis*	+	1	1	.	.	.	.	3
Blackstonia acuminata (W. D. J. Koch & Ziz) Domin subsp. *acuminata*	.	.	+	.	+	.	+	3
Salsola inermis L.	.	.	1	.	.	.	1	2
Lotus tenuis Willd.	.	.	.	.	.	1		1
Avena barbata Pott ex Link	.	.	.	.	.	+		1
Briza minor L.	.	.	.	.	.	r	.	1
Allium vineale L.	.	.	.	.	.	.	+	1
Bromus squarrosus L. subsp. *squarrosus*	.	.	.	+	.	.	.	1

Table 8. *Limonio narbonensis-Juncetum gerardi* Géhu et Biondi 1994.

Relevé number	28	29	30	31	32	Presence
Site	GE	GE	GE	GE	C	
Area (m²)	9	9	4	4	4	
Cover (%)	100	100	100	100	100	
Diagnostic of association						
Juncus gerardi Loisel. subsp. *gerardi*	4	3	2	2	1	5
Limonium narbonense Mill.	+	2	1	r	3	5
Charact. of higher units						
Aeluropus littoralis (Gouan) Parl. subsp. *littoralis*	+	1	2	2	+	4
Galatella tripolium (L.) Galasso, Bartolucci & Ardenghi	+	.	.	r	.	2
Limbarda crithmoides (L.) Dumort. subsp. *longifolia* (Arcang.) Greuter	.	.	+	+	.	2
Other species						
Suaeda maritima (L.) Dumort.	.	+	+	.	+	3
Bolboschoenus maritimus (L.) Palla	+	.	r	.	+	3
Polypogon monspeliensis (L.) Desf.	.	.	+	+	+	3
Salicornia perennis Mill. subsp. *perennis*	.	r	.	+	.	2
Helminthotheca echioides (L.) Holub	.	.	+	.	.	1
Plantago coronopus L.	.	.	r	.	.	1

Table 9. *Puccinellio festuciformis-Aeluropetum litoralis* (Corb. 1968) Géhu et Costa 1984 in Géhu et al. 1984 .

Relevé number	46	47	48	49	50	Presence
Site	GE	GE	GE	GE	GE	
Area (m²)	4	4	4	4	9	
Cover (%)	100	100	100	100	100	
Diagnostic of association						
Aeluropus littoralis (Gouan) Parl. subsp. *littoralis*	5	5	4	4	3	5
Puccinellia festuciformis (Host) Parl.	+	.	+	.	.	2
Charact. of higher units						
Galatella tripolium (L.) Galasso, Bartolucci & Ardenghi	r	+	.	.	.	2
Juncus maritimus Lam.	.	.	2	.	.	1
Limonium narbonense Mill.	.	.	r	.	.	1
Other species						
Bolboschoenus maritimus (L.) Palla subsp. *maritimus*	+	.	+	1	+	4
Juncus gerardi Loisel. subsp. *gerardi*	+	+	.	1	.	3
Polypogon monspeliensis (L.) Desf.	r	.	.	.	+	2
Artemisia caerulescens L. subsp. *caerulescens*	.	.	.	.	+	1

maritimus, can be encountered. This community can be attributed to the *Junco maritimi-Spartinetum junceae* association, already described for the Pisan coast where it is quite widespread in the wet sandy silt belts close to the dunes without marked salinity (Bertacchi and Lombardi 2014). Other reports of this association concern Lazio (Frondoni and Iberite 2002), Sardinia (Filigheddu et al. 2000), Sicily (Sciandrello et al. 2019), and the Adriatic coast (Pirone et al. 2014)

JUNCETUM MARITIMI-ACUTI Horvatic1934 (Tab. 11, Annex I Habitat: 1410).

The communities of *Juncus acutus* and *J. maritimus*, attributable to the association *Juncetum maritimi-acuti*, frequent and extended in all the humid sectors of the Pisan coast, can be found here almost exclusively in the Cornacchiaia area. This is due to the fact that naturally they would occupy those silt-sandy areas surrounding the Galanchio ponds but intended, instead, for cultivation.

Table 10. *Junco maritimi-Spartinetum junceae* (O. de Bolòs 1962) Filigheddu, Farris & Biondi 2000 .

Relevé number	58	59	60	61	
Site	GW	GW	GW	GW	Presence
Area (m²)	9	9	9	9	
Cover (%)	100	100	100	100	
Diagnostic of association					
Sporobolus pumilus (Roth) P.M.Peterson & Saarela	3	3	4	5	4
Juncus maritimus Lam.	+	2	1	.	3
Other species					
Carex divisa Huds.	+	.	+	.	2
Lotus tenuis Willd.	+	+	.	.	2
Periploca graeca L.	+	.	+	.	2
Carex extensa Gooden.	.	.	.	+	1
Holcus lanatus L.	+	.	.	.	1
Juncus articulatus L. subsp. *articulatus*	.	+	.	.	1
Ranunculus sardous Crantz	.	r	.	.	1
Tripidium ravennae (L.) H.Scholz subsp. *ravennae*	.	.	+	.	1
Linaria vulgaris Mill. subsp. *vulgaris*	+	.	.	.	1

Table 11. *Juncetum maritimi-acuti* Horvatic 1934 .

Relevé number	62	63	64	65	66	67	
Site	GW	GE	C	C	C	C	Presence
Area (m²)	9	9	9	9	9	9	
Cover (%)	100	80	80	100	100	100	
Diagnostic of association							
Juncus maritimus Lam.	3	1	2	3	+	+	6
Juncus acutus L. subsp. *acutus*	.	1	2	2	3	4	5
Charact. of higher units							
Galatella tripolium (L.) Galasso, Bartolucci & Ardenghi	+	1	1	+	.	.	4
Bolboschoenus maritimus (L.) Palla	.	.	.	.	+	1	2
Aeluropus littoralis (Gouan) Parl. subsp. *littoralis*	.	.	+	.	.	+	2
Limonium narbonense Mill.	.	.	.	.	1	.	1
Carex extensa Gooden.	.	.	+	.	.	.	1
Other species							
Polypogon monspeliensis (L.) Desf.	.	.	.	+	2	+	3
Symphyotrichum squamatum (Spreng.) G. L. Nesom	.	1	+				2
Lotus tenuis Willd.	.	1	.	+	.	.	2
Thinopyrum acutum (DC.) Banfi	1	.	+	.	.	.	2
Sporobolus aculeatus (L.) P.M.Peterson	.	.	+	.	r	.	2
Phragmites australis (Cav.) Steud.	.	+	.	.	.	.	1
Calystegia sepium (L.) R. Br.	.	.	+	.	.	.	1
Juncus gerardi Loisel. subsp. gerardi	.	.	1	.	.	+	1
Calamagrostis epigejos (L.) Roth	.	+	.	.	.	.	1
Allium vineale L.	r	.	.	.	.	.	1
Blackstonia acuminata (W. D. J. Koch & Ziz) Domin.	.	.	.	+	.	.	1
Tripidium ravennae (L.) H.Scholz subsp. *ravennae*	+	.	.	.	.	.	1
Lathyrus clymenum L.	r	.	.	.	.	.	1
Spergularia media (L.) C. Presl	.	.	.	.	+	.	1
Dactylis glomerata L.	+	.	.	.	.	.	1

Reported for Tuscany only in the southernmost station of Scarlino (Viciani et al. 2001), it is also cited for Lazio (Frondoni and Iberite 2002), Nord Adriatic coast (Piccoli 1995) and Sicily (Brullo and Sciandrello 2006).

Reedbeds dominated by *Phragmites australis* (Cav.) Steud (*Phragmito-Magnocaricetea*)

PHRAGMITETUM AUSTRALIS Savič 1926 *nom. mut. propos.* (Tab. 12).

The almost monophytic reed beds of *Phragmites australis* characterize and constitute the vegetal landscape of all the ditches and canals and frame the wetter and saltier areas of the study area. In these communities, corresponding to *Phragmitetum australis*, the cryptogenic *Periploca graeca*, characteristic of the nearby forests of *Fraxinus angustifolia* subsp. *oxycarpa* (Willd.) Franco & Rocha Afonso, often interpenetrates. The diffusion of *Periploca graeca* within helophytic vegetation has already been reported for nearby Massaciuccoli lake by Lastrucci et al. (2017).

Discussion and conclusions

This research highlighted the presence of halophilous communities in an agricultural area, on the edge of the protected area of the Migliarino San Rossore Massaciuccoli Park and strictly close to the harbour and industrial area of Livorno. The phytosociological analysis identified 3 habitats of Community interest and 12 associations. Between these, only one, *Phragmitetum communis*, can be considered extremely common and widespread throughout the Tuscany and national territory. All the other halophilous phytocoenoses here identified, are rather localized along the Tuscany coast and of limited extent.

These communities are completely disappeared and absent on the North of the Pisan coast. Only few surviving brackish areas are on the south. In this scenario, on the nine main brackish coastal areas known from literature, 26 associations were identified as well as other halophilous communities still to be framed from a phytosociological point of view (Fig. 5). Some of these areas, like San Rossore, require further surveys for data implementation or for their nomenclatural updating, while other brackish micro-areas are not yet investigated. Moreover, the need for constant monitoring of these areas, which are often subjected to high anthropogenic pressure, should be emphasized.

The associations of *Salicornietea* and *Thero-Salicornietea* identified in the study area are also present in other Tuscan coastal brackish contexts. Otherwise, two associations are here reported for the first time: *Puccinellio festuciformis-Aeluropetum litoralis* and *Juncetum maritimi-acuti* of *Juncetea maritimi*. This confirms the originality of the site. It should also be emphasized that in this area the species *Sporobolus aculeatus*, sporadically present in the nearby San Rossore Estate, gives rise to extensive phytocoenoses with high coverage density. The association *Cypsidetum aculeatae* is to be considered extremely rare for Tuscany. It is reported only for another station with very limited extensions and coverage, on the south of Piombino (Viciani and Lombardi 2001).

The ponds of Galanchio-Cornacchiaia, nowadays is isolated in the agricultural area and fragmented between the Selva Pisana to the north and the artificial canals network of the Navicelli-Scolmatore to the south. Therefore, it can be considered an environmental relict.

Much larger brackish areas once stretched between the coastal dunes and the southern forests of Tombolo. The only other partially brackish site in the area remains inside the Bosco dell'Ulivo. However, it is isolated from any contact with Galanchio-Cornacchiaia by the hydrographic and drainage network.

Table 12. *Phragmitetum australis* Savič 1926 *nom. mut. propos.*

Relevé number	68	69	70	71	Presence
Site	GW	GW	GE	GE	
Area (m²)	9	9	9	9	
Cover (%)	100	100	100	100	
Diagnostic species					
Phragmites australis (Cav.) Steud. subsp. *australis*	4	5	5	4	4
Other species					
Calystegia sepium (L.) R. Br.	+	+	.	+	3
Rubus ulmifolius Schott	1	+	.	+	3
Periploca graeca L.	+	+	.	.	2
Ranunculus sardous Crantz	.	.	r	.	1
Lythrum salicaria L.	.	.	.	r	1
Geranium dissectum L.	.	.	r	.	1
Samolus valerandi L.	.	r	.	.	1
Scirpoides holoschoenus (L.) Soják	+	.	.	.	1
Polypogon monspeliensis (L.) Desf	.	.	+	.	1
Bolboschoenus maritimus (L.) Palla	.	.	.	1	1
Juncus maritimus Lam.	r	.	.	.	1

	1	2	3	4	5	6	7	8	9
Arthrocnemum glauci Br.Bl.1928 (i)								*	
Crypsidetum aculeatae (Bojko 1932 n. n.) Wenzl 1934 (d,f)		*			*				
Elytrigio elongatae-Inuletum crithmoidis Br.-Bl. (1931) 1952 (d,f,g,h)		*			*	*	*		
Halocnemum strobilacei (Keller) Topa, 1938 (i)								*	
Limbardo crithmoidis-Limonietum etrusci Viciani, Foggi &Ferretti (l)				*					
Limonio narbonensis-Artemisietum coerulescentis Horvatić (1933) 1934 corr. Géhu & Biondi 1996 (h)							*		
Limonio narbonensis-Puccinellietum festuciformis (Pign. 1966) Géhu et Scoppola in Géhu et al. 1984) (f,k)					*				*
Limonio narbonensis-Juncetum gerardii Géhu et Biondi 1994 (b,d,f)	*	*			*				
Parapholidetum filiformis Brullo, Scelsi et Siracusa 1994 (d)		*							
Parapholido incurvae-Frankenietum pulverulentae Riv.-Mart. ex Castroviejo & Porta 1976 (k)									*
Puccinellio festuciformis-Aeluropetum litoralis (Corb. 1968) Géhu et Costa 1984 in Géhu et al. 1984 (d)		*							
Puccinellio convolutae-Arthrocnemetum macrostachyi (Braun-Blanquet (1928) 1933) Géhu in Géhu, Costa, Scoppola, Biondi, Marchiori, Peris, Franck, Caniglia & Veri 1984 (h,k)							*		*
Puccinellio festuciformis-Halimionetum portulacoidis Géhu, Biondi, Géhu-Franck et Costa 1992 (d,f,g,h,k)		*			*	*	*		*
Puccinellio festuciformis-Sarcocornietum perennis (Br.-Bl. 1931) Géhu 1976 (d,f,h,k)		*			*		*		*
Puccinellio festuciformis-Scirpetum compacti (Pign. (1953) 1966) (f)					*				
Puccinellio-Juncetum maritimi (Pign. 1953) (h)							*		
Salicornietum emerici (Bolós 1962) Brullo & Furnari 1976 (k)									*
Salicornietum radicantis Br.Bl., 1931 (i)								*	
Salsoletum sodae Pignatti 1953 (f)					*				
Sarcocornietum deflexae (Br.-Bl. 1931) Lahondère, Géhu & Paradis 1992 (g)						*			
Scirpo-Juncetum subulati Géhu et al. 1992 (f)					*				
Spergularietum salinae Molinier &Tallon 1969 (k)									*
Suaedo maritimae-Salicornietum patulae (Brullo et Furnari 1976) Géhu et Géhu-Frank 1984) (b,d,f,g,h,k)	*	*			*	*	*		*
Juncetum maritimi–acuti Horvatic1934 (d,h)		*					*		
Junco maritimi-Spartinetum junceae O. de Bolòs 1962 (nom. inv. prop. Filigheddu, Farris et Biondi 2000) (d)		*							
Arthrocnemum glaucum communities (e)			*						
Limonium narbonense communities (a,b,c)	*								
Salicornia patula and others halophyte communities (a)	*								

a (Tomei et al., 2004); **b** (Sani e Tomei, 2006); **c** (Bertacchi et al., 2007); **d** (Bertacchi et al., this work); **e** (Coaro, 1987); **f** (Viciani e Lombardi, 2001); **g** (Foggi et al. 2006); **h** (Viciani et al. 2001); **i** (Arrigoni et al., 1985); **k** (Andreucci, 2004); **l** (Viciani et al., 2012)

Figure 5. List and distribution of halophilous associations and phytocoenotic communities found to date in the nine main brackish coastal areas known from the literature for of the Tuscan coast.

This environments are still constantly under anthropic pressure. The immediately surrounding areas of the two ponds of Galanchio are annually affected by agricultural work with mechanical means, which do not allow any expansion of natural vegetation. The Cornacchiaia pond is periodically disturbed by the consolidation and maintenance of the embankments of the Canale dei Navicelli on its southern edge.

As a consequence of all this, the halo-hygrophilous vegetation of this area, appears mainly disturbed, fragmented and often brought back to primary successional stages, despite showing a high resilience to anthropogenic pressure. This prevents the expansion and the natural dynamic of the vegetation. In the absence of disturbance and with management policies of greater protection, this site could evolve (or return) towards a biotope of greater biocenotic complexity and floristic richness.

Statements

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Syntaxonomic scheme

PHRAGMITO-MAGNOCARICETEA Klika in Klika & Novák 1941
PHRAGMITETALIA Koch 1926
Phragmition communis Koch 1926
Phragmitetum australis Savič 1926 *nom. mut. propos.*

JUNCETEA MARITIMI Br.-Bl. in Br.-Bl. et al. 1952
JUNCETALIA MARITIMI Br.-Bl. ex Horvatic 1934
Juncion maritimi Br.-Bl. ex Horvatic 1934
Junco maritimi-Spartinetum junceae O. de Bolòs 1962 (nom. inv. prop. Filigheddu, Farris et Biondi 2000)
Juncetum maritimi-acuti Horvatic1934
Elytrigio elongatae-Inuletum crithmoidis Br.-Bl. (1931) 1952
Limonio narbonensis-Juncetum gerardi Géhu et Biondi 1994
Puccinellio festuciformis-Aeluropetum litoralis (Corb. 1968) Géhu et Costa 1984 in Géhu et al. 1984

SAGINETEA MARITIMAE Westhoff, Van Leeuwen et Adriani 1962
FRANKENIETALIA PULVERULENTAE Rivas-Mart. ex Castroviejo et Porta 1976
Frankenion pulverulentae Rivas-Mart. ex Castroviejo et Porta 1976
Parapholidetum filiformis Brullo, Scelsi et Siracusa 1994
CRYPSIDETALIA ACULEATAE Vicherek 1973
Crypsidion aculeatae Pign. 1954
Crypsidetum aculeatae (Bojko 1932 n. n.) Wenzl 1934

SALICORNIETEA FRUTICOSAE Br.-Bl. et Tx. ex A. Bolòs y Vayreda et O. de Bolòs in A. Bolòs y Vayreda 1950
SALICORNIETALIA FRUTICOSAE Br.-Bl. 1933
Salicornion fruticosae Br.-Bl. 1931
Puccinellio festuciformis-Sarcocornietum perennis (Br.-Bl. 1931) Géhu 1976
Puccinellio festuciformis-Halimionetum portulacoidis Géhu, Biondi, Géhu-Franck et Costa 1992

THERO-SALICORNIETEA Tx. in Tx. et Oberd. 1958
THERO-SALICORNIETALIA Pignatti 1952
Therosalicornion Br.-Bl. 1933
Suaedo maritimae-Salicornietum patulae (Brullo et Furnari 1976) Géhu et Géhu-Franck 1984
Suaedetum maritimae (Cornad 1935) Pignatti 1953

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